Vertical Circulation Off the Ross Ice Shelf

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ABSTRACT: The Ross Ice Shelf is a floating ice mass about 200 m thick over an average depth along the barrier of 567 m. In January the prevailing wind blows from the east, parallel to the coast. The wind current transports the low salinity layer (ca. 50 m) toward the ice shelf, where it must descend. Directly off the barrier we find low salinities to a depth of 150 m. The circulation here is quite similar to that defined by Sverdrup along the shelf ice of Queen Maud Land. Because of sinking of the low salinity layer near the barrier, diatoms live in abundance at subcompensation depths, *Trigonium arcticum* actually on the sea bed.

THE SOUTHERN BOUNDARY of the Ross Sea is fringed by floating ice of the Ross Ice Shelf except for the relatively small McMurdo Sound–Ross Island area. The clifflike barrier of the ice shelf is about 200 m thick (Sullivan, 1957). An average of 35 m rises from the surface of the water and about 165 m are submerged. The average depth along the barrier is 567 m. The width of the shelf in places exceeds 1300 km. Since water can circulate beneath this huge ice mass we can expect unique features of circulation.

The Ross barrier is washed by the Circumpolar Countercurrent which is produced partly by the distribution of density and partly by the prevailing wind. This current is usually weak along the barrier, but as it sweeps around Cape Adare it often attains a velocity of about 3 knots (author's observation). The data shown in Table 2 for station G–1 indicate that at this station a weak current is flowing toward the east. This supports the postulation of Kort (1962), who projected such a current through the vicinity of this station.

In all, three stations were taken off Kainan Bay (Ross Ice Shelf) along a north-south line at distances of 0, 40, and 156 km (Fig. 1). Two of these were taken in EDISTO and one in GLACIER. The work was carried out under the general supervision of Dr. Willis L. Tressler of the U. S. Navy Oceanographic Office. Several vertical plankton tows were made with a 20-mesh closing net at stations Ed–1 and Ed–2. The water column was sampled at all three of these stations. The results of these casts are shown in Tables 1[2] and 2 respectively.

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[2] Because of the wide variation in the size of biota the terms many, common, and few are used to connote relative quantitative abundance.

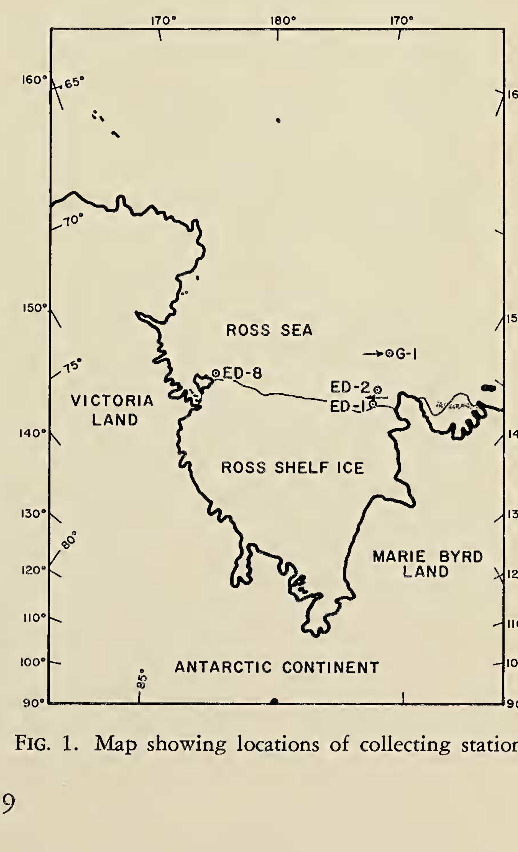

FIG. 1. Map showing locations of collecting stations.

TABLE 1

INCIDENCE OF PLANKTON AS A FUNCTION OF DEPTH AT ROSS SEA STATIONS

ORGANISM	DEPTH AND INCIDENCE 0–100 m	100–200 m	200–300 m	300–400 m
Station Ed–1. Kainan Bay entrance. 78°10'S, 161°56'W. 0200 January 21, 1956. Depth, 732 m. Algae present throughout water column.				
Coscinodiscus borealis	few	none	few	none
Coscinodiscus janishu	few	none	none	none
Coscinodiscus sp. A	many	few	common	common
Corethron criophilum	many	many	common	common
Streptotheca thamenis	few	none	none	none
Hemiaulis membranecus	common	none	none	none
Eucampia valasistum	few	none	none	none
Eucampia zoodiaius	few	none	none	none
Fragilariopsis antarctica	common	common	none	none
Thalassiosira sp.	common	none	common	none
Nitzschia seriata	few	none	none	none
Rhizosolenia alta	common	none	none	none
Rhizosolenia calcai avis	common	none	few	none
Peridinium depressum	few	none	few	none
Copepods	none	common	many	few
Nauplii	none	common	many	few
Veligers	none	none	few	none
Station Ed–2. 40 km north of Kainan Bay. 77°44'N, 162°12'W. 1200 January 28, 1956. Depth, 700 m. Algae present in upper layers.				
Coscinodiscus borealis	few	none	none	none
Coscinodiscus janishu	many	none	few	none
Coscinodiscus sp. A	common	none	few	none
Corethron criophilum	many	none	few	none
Streptotheca thamenis	few	none	none	none
Hemiaulus membranecus	common	none	none	none
Eucampia zoodiaius	few	none	none	none
Fragilariopsis antarctica	common	none	none	none
Nitzschia seriata	few	none	none	none
Rhizosolenia calcai avis	many	none	none	none
Peridinium depressum	few	none	none	none
Tintinnids	few	none	none	none
Copepods	none	none	many	none
Nauplii	none	none	many	none
Veligers	none	none	few	none

TABLE 1 (continued)

Station Ed–8. Off Cape Crozier. 77°29'S, 169°34'E. 0600 February 28, 1956. Depth, 300 m. Algae present throughout water column.

Coscinodiscus borealis	few	none	none
Coscinodiscus janishu	few	few	few
Coscinodiscus sp. A	few	none	none
Coscinodiscus sp. B	common	few	few
Corethron criophilum	many	common	common
Eucampia valasistum	few	none	none
Trigonium arcticum	none	none	many
Thalassiosira hyalina	few	none	none
Thalassiosira sp.	few	none	none
Fragilariopsis antarctica	few	few	none
Disephanus speculum	common	few	few
Peridinium depressum	many	none	none
Tomopteris sp.	few	none	none
Copepods	common	few	many
Nauplii	many	many	many
Veligers	many	none	none

In addition to the three stations mentioned above one (Ed–8) was taken 1 km off Cape Crozier, Ross Island (Fig. 1). Opportunity did not permit taking additional stations offshore along the same meridian, normal to the current.

The populations shown in Table 1 were living when taken and examined at stations Ed–1 and Ed–8. They were preserved for later examination at station Ed–2. The presence of diatoms at depths of 200–300 m and deeper engendered a desire to inquire into the reason for this apparent phenomenon.

The author is grateful to Dr. W. L. Tressler and to Mr. J. Q. Tierney, both of the U. S. Navy Oceanographic Office, for data and help in identifying biota.

DISCUSSION

According to Sverdrup (1953*a*) the threshold requirement in energy for *Coscinodiscus excentricus* is 0.002 lys. min^{-1}. Schreiber (1927) calculated 0.00172 lys. min^{-1} for *Biddulphia mobiliensis,* the lowest energy requirement for a diatom of which there is a record. No micrometeorological data were taken. However, List's tables (1951) show an albedo of 14% under average conditions similar to those which existed off the Ross Ice Shelf at the time of observation on January 21, with 0.383 lys. min^{-1} refracted into the sea. Considerably less energy reached Cape Crozier on February 28—1 month later. To determine the compensation depth, the coefficient of absorption for visible radiation is calculated from the Poole-Atkins (1929) equation:

$$-k = 1.17.D^{-1}$$

where D = transparency by secchi disk (in meters).

$$-k = 4.2 \times 10^{-3} \text{ cm with a transparency of 4.}$$

The compensation depth is found from the equation:

$$z = (1/-k) \ln (I_z/_o)$$

where I_z = threshold requirement in energy (1.72×10^{-5} lys. min^{-1}), and I_o = energy refracted into the sea (3.83×10^{-1} lys. min^{-1}).

Then: $z = -12.65$ m (compensation depth).

Because transparency in Antarctic waters is primarily a function of population densities, $-k = 4.2 \times 10^{-3}$ is valid only for the upper 4 m. However, considering the density of populations at lower depths, it is axiomatic that *Corethron criophilum,* for example, cannot be fixing carbon by photosynthesis at depths in excess of 300 m. Still, at station Ed–1 this diatom and *Coscinodiscus* sp. A occurred throughout all sampled layers of the water column. At sta-

TABLE 2

PHYSICAL ENVIRONMENT OF ANTARCTIC OCEAN PLANKTON STATIONS

DEPTH (meters)	TEMPERATURE (°C)	SALINITY (o/oo)	6t	ΣΔD	OXYGEN (ml/l)
Station Ed–1. Entrance of Kainan Bay. Color, 20. Transparency, 4.					
Surface	–0.50	33.93	2729	0000	10.94
50	–1.25	34.08	2744	0036	8.88
100	–1.66	34.15	2751	0066	8.22
150	–1.87	34.21	2756	0094	8.45
200	–1.91	34.22	2757	0120	8.48
300	–1.87	34.35	2767	0166	8.04
400	–1.83	34.39	2770	0205	7.85
500	–1.82	34.38	2770	0243	7.99
600	–1.83	34.47	2783	0277	7.90
Station Ed–2. 40 km north of Kainan Bay. Color, 20. Transparency, 4.					
Surface	0.47	34.21	2746	0000	10.59
50	–1.37	34.22	2755	0031	9.25
100	–1.78	34.27	2761	0056	8.23
150	–1.86	34.32	2765	0079	8.31
200	–1.88	34.39	2770	0100	8.04
Station G–1. 156 km north of Kainan Bay. Color, 14. Transparency, 9.					
Surface	–0.93	34.11	2745	0000	not
50	–0.60	34.15	2750	0030	observed
100	–1.72	34.23	2757	0057	
150	–1.75	34.29	2762	0082	
200	–1.79	34.32	2764	0104	
250	–1.85	34.31	2764	0127	
300	–1.89	34.31	2764	0149	
Station Ed–8. 1 km off Cape Crozier. Color, 20. Transparency, 3.					
Surface	–1.39	34.20	2754	0000	9.97
50	–1.39	34.27	2760	0026	9.88
100	–1.28	34.43	2772	0047	9.40
150	–1.16	34.31	2762	0068	9.60
200	–1.27	34.35	2766	0091	8.68
300	–1.86	34.54	2783	0119	8.61

tion Ed–8, off Cape Crozier, the diatom *Trigonium arcticum* was found only in the 200–300 m (bottom) cast. Moreover, it occurred in bottom surface samples together with fragments of decaying algae.

An investigation was then made of vertical circulation at station Ed–1, to determine if sinking could account for these biota living beneath the compensation depth. According to Vowinckel (1957) the prevailing wind at Kainan Bay (Little America), Ross Ice Shelf, is easterly during the month of January. Considering the magnitude of the Coriolis force at this high latitude, it seems the light shallow layer would be transported toward the shelf ice under the influence of the wind stress. Continuity, then, requires a descending motion off the ice shelf. According to Sverdrup (1953*b*) this means that close to an ice shelf we can expect a thick layer of water of low salinity.

To determine the *rate* of sinking at station Ed–1, the procedure of Sverdrup (1953*b*) in his investigation of vertical transport of water in the vicinity of the ice shelf at Maudheim (Antarctica) was used:

$$T = \tau \,(s\, 2\, \omega \sin \phi)^{-1} \quad (1)$$

where τ = stress of the wind, s = water density, ω = angular velocity of the earth, ϕ = latitude of the observer.

$$\tau = V^2 s^i . K. \quad (2)$$

where V = wind velocity, cm sec^{-1}, s^i = density of the air, K = factor of proportionality = 2.6×10^{-3}.

The equation becomes:

$$T = Ks^iV^2 \,(s\, 2\, \omega \sin \phi)^{-1} \quad (3)$$

According to Vowinckel (1957) the prevailing wind at Kainan Bay (Little America) during the month of January is easterly. The average velocity is 10 knots or 510 cm sec^{-1}. Assuming this value for V and 78° for ϕ we obtain:

$$T = 7.0 \times 10^3 \text{ cm}^3 \text{ sec}^{-1} \quad (4)$$

where T = total volume of transport across a 1 cm-wide surface.

If sinking takes place uniformly from the barrier to an arbitrary distance of 10 km (= 10^6 cm), the average downward velocity will be 7.0×10^{-3} cm sec^{-1}. At this velocity water requires 14×10^6 seconds, or about 16 days, to sink 100 m. This is comparable with Sverdrup's calculation (1953*b*) of 20 days for 150 m at Maudheim. Probable circulation is shown in Figure 2.

Vertical circulation on the above scale can explain the presence of diatoms at subcompensation depths and elsewhere throughout the water column at Ed–1. While Cape Crozier is adjacent to the Ross Ice Shelf, a somewhat different pattern of circulation can be expected along a land

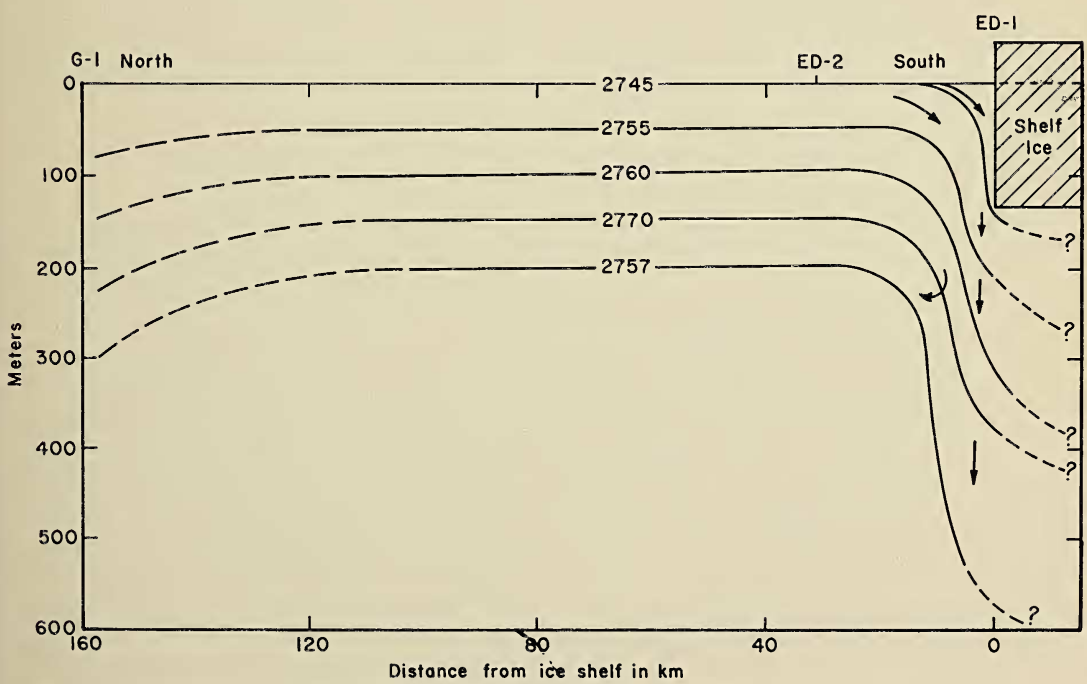

FIG. 2. Vertical section at right angles to the coast line in about 162°W, showing isopycnic lines. Probable vertical circulation is indicated.

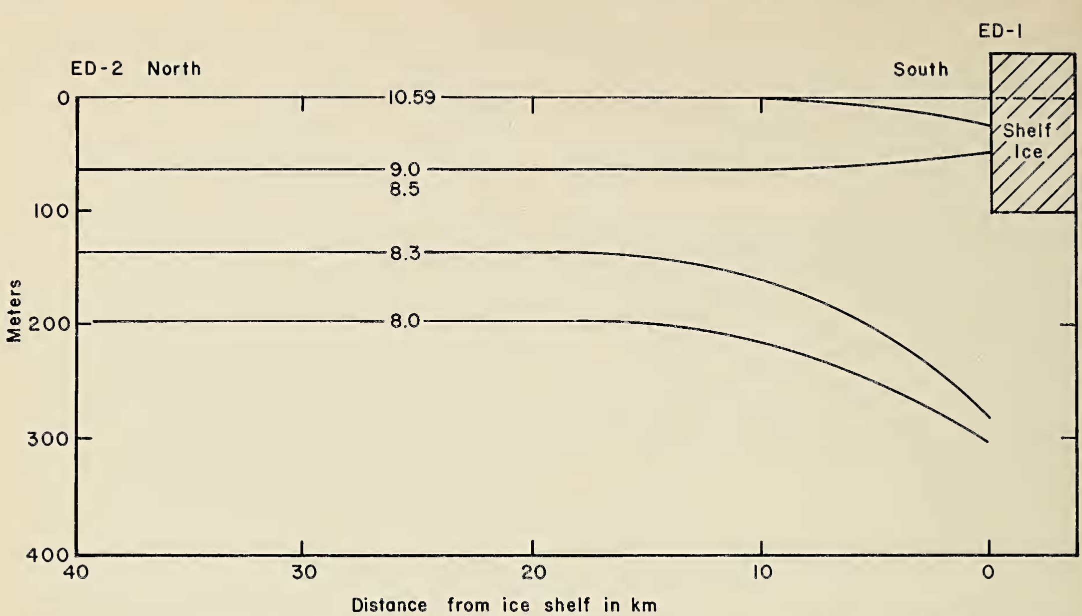

FIG. 3. Vertical section at right angles to the coast line in about 162°W, between stations Ed–1 and Ed–2 showing distribution of oxygen in ml/L.

mass. But plankton would, nonetheless, be swept past it in all layers. However, the diatom *T. arcticum* is found only on the bottom and nowhere else in the water column.

According to Hendy (1937) many specimens of *T. arcticum* spend most of the time as bottom forms and seldom get into the plankton. At several stations in Vincennes Bay the author found many on the bottom and none in the plankton. Hendy also mentions that many specimens are epiphytic on algae. How then can this plant fix carbon in the absence of radiant energy?

The fact that algae which appear to be decomposing are found in association with *T. arcticum* suggests the possibility of saprophytic nutrition. According to Kudo (1954) organisms (for example, *Euglena gracilis* and *Chilomonas paramecium*) receive saprophytic nutrition by diffusion through the body surface. This is accomplished without any organellae. There is only one known exception—marine dinoflagellates—in which saprophytic nutrition is accomplished through a special organella. According to Dr. E. W. Putman[3] (conversation), *T. arcticum* may well be a saprophyte when not photosynthesizing.

An interesting by-product of this investigation is shown in Figure 3. The high content of oxygen in the surface layers is probably due to the abundant population of holophytic organisms.

CONCLUSIONS

The circulation pattern off the Ross Ice Shelf is nearly identical with that found by Sverdrup (1953*b*) to exist off the shelf ice of Queen Maud Land.

It is obvious to anyone interested in plankton ecology that organisms at subeuphotic depths cannot fix carbon and cannot be holophytic. Hence, *Trigonium arcticum,* under the conditions in which it was found, cannot fix carbon and be holophytic. This fact has been known at least since 1937 (Hendy). Still, no attempt has been made to explain how such plants do manage to live in virtual extinction of visible radiation. It is likely, then, that this diatom, and possibly others, may be capable of using chemical energy derived from decaying algae as a means of nutrition.

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REFERENCES

HENDY, N. INGRAM. 1937. The plankton diatoms of the southern seas. Discovery Rept., XIII:151–364, pls. 6–13.

KORT, V. G. 1962. The Antarctic Ocean. Scientific American 207(3):113–128.

KUDO, RICHARD R. 1954. Protozology, p. 108. Chas. C. Thomas, Springfield, Ill.

LIST, ROBERT J. 1951. Smithsonian Meteorological Tables. 6th ed. Smithsonian Misc. Coll. 114.

POOLE, H. H., and W. G. R. ATKINS. 1929. Photoelectric measurements of submarine illumination throughout the year. J. Mar. Biol. Assoc., U. K. 16(1):297–324.

SCHREIBER, S. 1927. Die Reinkultur von marinen Phytoplankton und deren Bedeutung für die Erforschung der Produktions-fahigkeit des Meerwassers. Wiss. Meersunters Heligoland 16(10):1–34.

SULLIVAN, WALTER. 1957. Quest for a Continent, p. 3. McGraw-Hill Book Co., N.Y.

SVERDRUP, H. U. 1953*a*. On conditions for the vernal blooming of phytoplankton. J. Conseil Intern. pour l'Exploration de la Mer 18(3): 287–295.

——— 1953*b*. The currents off the coast of Queen Maude Land. Saertrykk av Norsk Geografisk Tidsskrift XIV, h. 1–4:239–249.

VOWINCKEL, E. 1957. Climate of the Antarctic Coast. Wea. Bur., Dept. Trans., So. Africa, Meteorol. Rept. of Antarctica, pp. 137–152.